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Research on Reservoir Application Allocation based on Nonlinear Prediction and Genetic Algorithm

Zuhan Wang

School of Economics, Harbin Normal University, Harbin, Heilongjiang, 150500, China

Abstract

Aiming at the problem of reservoir supply distribution in the southwestern United States this year, this paper aims at the water distribution between Glenn Canyon Dam (Lake Powell) and Hoover Dam (Lake Meade). A nonlinear programming model is established to optimize the pumping allocation of each dam, and the model is upgraded and extended to multiple scenarios to closely coordinate the operation of the two dams. First of all, based on the nonlinear programming model, the geomorphological environment, policy changes, time lapse and other factors that may affect the water demand and electricity consumption of the five states are quantified and analyzed, and the water consumption and electricity consumption data of the five states are obtained. Then a nonlinear programming model is established to maximize benefits while meeting the water and electricity needs of the five states, and the multivariate function optimization flow chart is derived by using genetic algorithm, and finally the optimal solution of the water level of the two lakes after pumping is obtained. And finally carry on the sensitivity to the change of the surrounding conditions. The sensitivity analysis results of the model show that the model used in this paper has the characteristics of high accuracy, good stability and wide application range, and has important application value.

Keywords

Water Scheduling; Nonlinear Programming; Genetic Algorithms; First Law of Thermodynamics.

1. Introduction

The construction of dams and reservoirs is a means of managing water supplies. Reservoirs can be used to store water for a variety of uses[1], provide an area for recreation and entertainment, help prevent downstream flooding, and provide water for turbines that generate electricity. With climate change, the volume of water from sources feeding dams and reservoirs is decreasing in many areas. Consequently, dams may not be able to meet the demands for water in these areas. Additionally, low water flow decreases the amount of electricity generated from hydroelectric plants resulting in disruptions of the power supply in these areas.

Natural resource officials in the U.S. states of Arizona (AZ), California (CA), Wyoming (WY), New Mexico (NM), and Colorado (CO) are currently negotiating to determine the best way to manage water usage and electricity production at the Glen Canyon and Hoover dams to address these competing interests[2]. Hundreds of years ago, agreements allocated more water from the Colorado River system than the system currently had. If drought conditions continue in the Colorado River basin, the water volume at some point will be insufficient to meet the basic water and generated electricity needs of stakeholders. Consequently, a rational, defensible water allocation plan for current and future water supply conditions is critically important.

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2. Collection of Data

Lake Powell and Lake Mead, located in the arid southwestern region of the United States, are the two major reservoir dams in the United States[3], and their water storage and hydroelectric power generation over the years have provided the majority of the water and electricity used for living and production in the surrounding areas. Due to the severe water level decline in recent years, regulating the water supply distribution within them is of great significance to the five surrounding states. Planning for water use at Glen Canyon and Hoover dams requires a clear understanding of the water needs of the areas involved and the amount of power resources required.

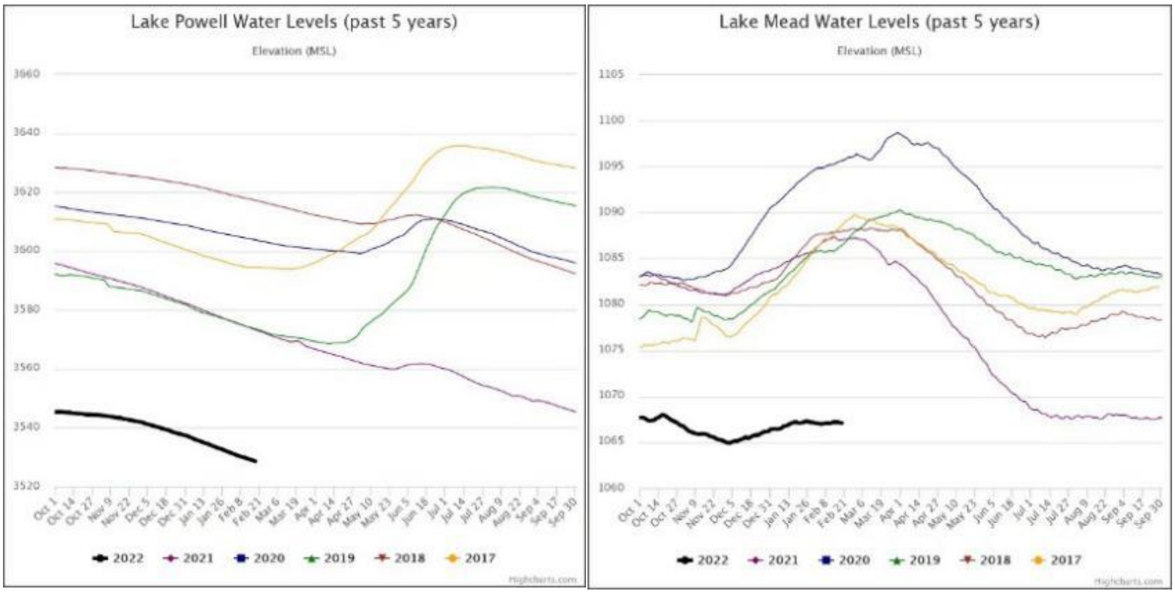

Fig.1 Lake related information

3. Nonlinear Model Optimization

3.1 Model Establishment

To determine the decision variables, the unknown variable required is the pumping volume of the two dams[4]. We assume here that the volume of the two lakes is roughly columnar, then the calculation of the pumping volume requires knowledge of the lake surface area and the water level. We can assume that the surface areas of Lake Powell and Lake Mead are constant A1, A2 and then assume that Pmin, Pmax are the dead and maximum water levels of Lake Powell and Mmin, Mmax are the dead and maximum water levels of Lake Mead, and use x1, x2, x3, x4 to represent the water level heights of Lake Powell before and after pumping and the water level heights of Lake Mead before and after pumping, respectively[5].

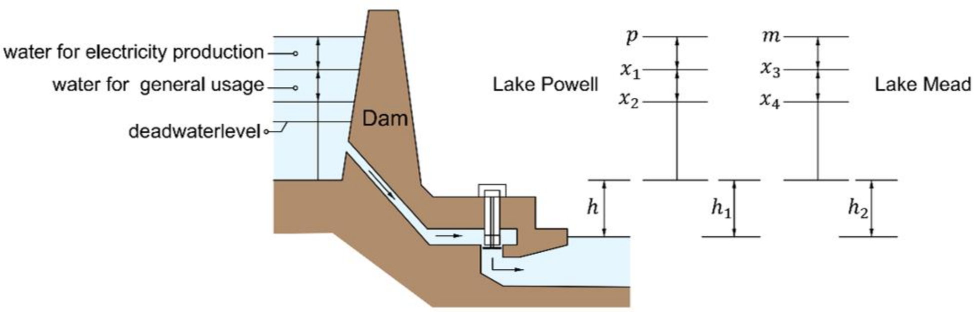

Fig.2 Lake tectonic model

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Determine the constraints, which in this case can be limited by the electricity and water consumption of the five states, as well as the minimum and maximum water levels of the two lakes, assuming that the water pumped out of the two DAMS is used first for electricity generation and then for water supply[6], using v1, v2 to represent the amount of water used in Lake Powell for power generation and water supply. In the same way, using v3, v4 to represent the amount of water used in Lake Mead for power generation and water supply. Assuming that the total water used in the five states is a, the amount of hydroelectric power needed for the five states is b, the maximum amount of water provided by the two reservoirs is c[7], the height between the bottom of the lake and the downstream water surface is h:

Lake Powell Water Supply(as example): v1=(x1-x2)A1.

Electricity generated by water from Lake Powell for electricity generation:

$$\lambda = \rho_{\text{water}} g_{x1} \int_1^p A_1 \left(h + h_1\right) dh = A_1 \rho_{\text{water}} g \left(\frac{1}{2} P^2 + P h_1 - \frac{1}{2} x_1^2 - x_1 h_1 \right) \tag{1}$$

Electricity generated by water from Lake Mead for power generation:

$$\mu = v_3 = \rho_{\text{water?}} g_{x_3} \int^m A_2 \left(h + h_2\right) dh_1 = A \rho_{\text{water?}} g \left(\frac{1}{2} M^2 + M h_2 - \frac{1}{2} x_3^2 - x_3 h_2 \right) \tag{2}$$

Hydroelectric power demand: $\lambda + \mu \geq b$.

Water consumption: $v_1 + v_2 \geq a$.

Lake Powell water level: $P_{\min} \leq x_2 \leq P \leq P_{\max}$.

Lake Mead water level: $M_{\min} \leq x_4 \leq M_{\max?}$.

Determining the objective function, the goal of is to achieve a best allocation scheme for the pumping water in the two lakes.

$$\min f(x) = A_1 \left(P - x_2\right) + A_2 \left(M - x_4\right) \tag{3}$$

If no additional water is supplied (from rainfall, etc.), and considering the demands as fixed, regarding the time to meet the demand:

Assuming that the time for Lake Powell and Lake Mead to meet local demand is t1, t2 and the time is related to the corresponding φ_1, φ_2 (one hour drainage of lake), the formula can be obtained:

Lake Powell: $t_1 = \frac{V_1 + V_2}{\varphi_1}$.

Over time, these fixed demands will require additional supplies of water if they are to be assured of being met. We use the time it takes to meet the water needs of the five states for a day compared to the length of a day, 24 hours, and the comparison results in the variable , from which we determine whether (δ) additional water is needed.

Lake Powell: n1=t1/24.

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When $n_1 \geq 1, n_2 \geq 1$, no additional water supply is required for the day. When $n_1 \leq 1, n_2 \geq 1$ or $n_1 \geq 1, n_2 \leq 1$, the additional water supply $\delta = v_1 + v_2 - \varphi_1 \times 24$ or $\delta = v_1 + v_2 - \varphi_2 \times 24$. When $n_1 < 1, n_2 < 1$, the additional water supply $\delta = v_1 + v_2 + v_3 + v_4 - (\varphi_1 + \varphi_2) \times 24$.

3.2 Model Solution

The optimal solution of the model is solved using a genetic algorithm, programmed by matlab, which simulates the processes of natural selection and the replication crossover and mutation that occur in heredity. Procedure. The objective function is transformed into an fitness function, and for the objective function minimization problem, such that : $_{Fitness}\left(f(x)\right) = \begin{cases} c_{\max} - f(x), c_{\max} > f(x) \\ 0, \text{other} \end{cases}$.

Select individuals with high fitness, which essentially simulates the natural doctrine of 'selection by selection' the greater the fitness, the greater the probability of being selected, with probability: The selected individuals are selected for crossover, variation and other operations until the optimal solution is searched:

$$\mathrm{p}(x_i) = \frac{f(x_i)}{\sum_{j=1}^{N} f(x_j)} \tag{4}$$

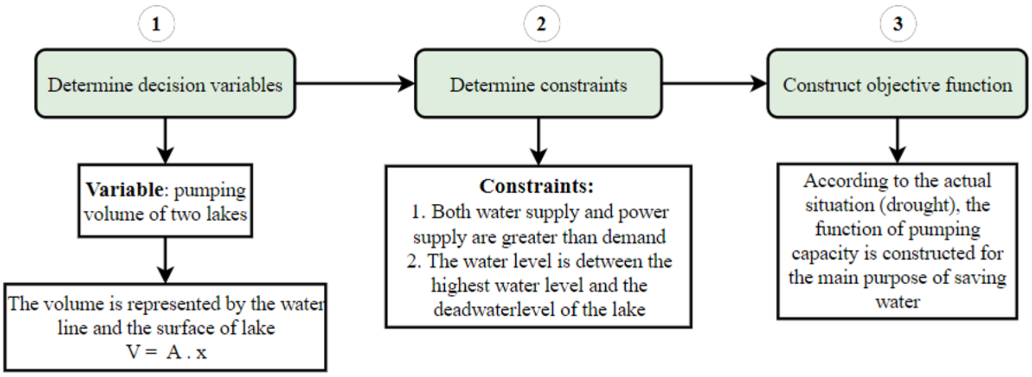

Fig.3 Solving process

Table 1. Model result

Symble	Unit	result
b	af	243320
a	af	3001854
δ	af	1245974
x_2	ft	984.6
x_1	ft	3531.4
T	h	36.1

4. Water& Power Supply and Distribution Model

4.1 Model Establishment

Generally speaking, a benefit indicator is needed to judge whether a project is worth putting in and running, and this benefit indicator is influenced by various aspects such as policy, economy, ideology and culture of each country, and is subjective in nature, so we will not discuss it here, but set this benefit indicator as a coefficient in a macro sense. Then we can use α and β to represent the indicator of interest of water resources for general (agricultural, industrial, residential) use and electricity production.

When the water in the reservoir meets the water supply and power supply and there is a surplus, the surplus we choose to allocate to the party with higher interest.

Step 1: Determine the decision variables and constraints. Namely the height of the water level before and after the pumping of the two dams, as well as the electricity and water consumption in the five states, and the minimum and maximum water levels in the two lakes.

Step 2: Determine the objective function.

$$y=\frac{\lambda+\mu}{b}+\frac{A_1\left(x_1-x_2\right)+A_2\left(x_3-x_4\right)}{a} \tag{5}$$

$$y_{\max}y_{\text{Interests}}=\alpha\left(A_1\left(x_1-x_2\right)+A_2\left(x_3-x_4\right)\right)+\beta(\lambda+\mu) \tag{6}$$

4.2 Result and Analysis

Table 2. Model result

Symble	Unit	result
x_1	ft	3525
x_2	ft	3498
x_3	ft	1112
x_4	ft	895

Due to the different development conditions in different regions, the benefit index of power will be greater in areas with large power demand, and the benefit index of general water use will be greater in areas with developed agriculture. Different models are used for different water resource allocation according to different conditions in different states.

5. Urgency and Model Analysis of Water supply demand

Fig.4 map of the United States

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According to the topographic map of the United States, the southwest region of the five states is steeper and higher than other regions where have water sources. It is very difficult and costly to transfer water from these regions. Therefore, when the demand for power supply and water supply is not met, priority shall be given to meeting the demand for water supply (the water used for power generation is used for water supply to ensure that the demand for water supply is met). The missing electricity is produced by other means, for example, wind power, solar power, nuclear power, thermal power, etc.

5.1 Model Establishment

Determining constraints:

$$s.t.\begin{cases} A_1\rho g\left(\frac{1}{2}P^2+P h_1-\frac{1}{2}x_1^2-x_1h_1\right)+A_2\rho g\left(\frac{1}{2}M^2+M h_2-\frac{1}{2}x_3^2-x_3h_2\right)<b \\ c\ge A_1(x_1-x_2)+A_2(x_3-x_4)\ge a \\ P_{\min}\le x_2\le P\le P_{\max} \\ M_{\min}\le x_4\le P_{\max} \end{cases} \tag{7}$$

Determine the objective function; the objective is to minimize the amount of water extracted in the case of the less power is missing, then the objective function can be established as follows:

$$\begin{gathered} \min f(x)=A_1\left(P-x_2\right)+A_2\left(P-x_4\right) \\ \min Q_{supply}=b-(\lambda+\mu) \end{gathered} \tag{8}$$

5.2 Model Solution

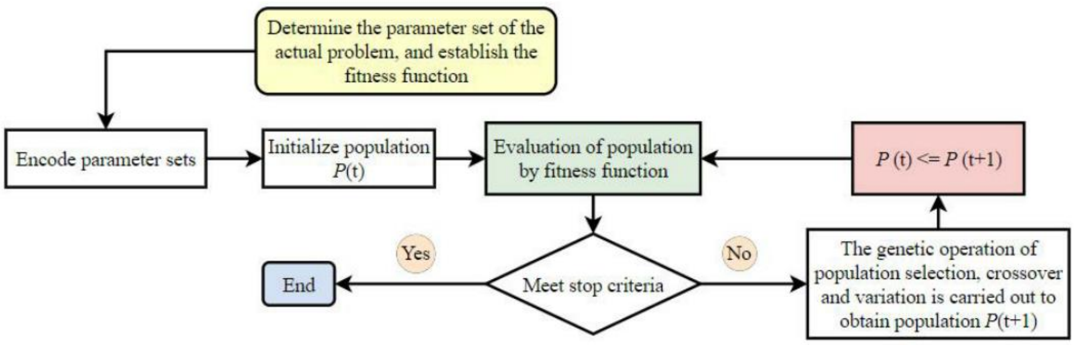

Fig.5 Model flow

Table 3. Model result

Symble	Unit	result
x_1	ft	3525
x_2	ft	3498
x_3	ft	1112
x_4	ft	895

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According to the results of the solution, we can calculate the electricity that needs to be supplemented, and then select the most suitable power generation mode for each state according to the geographical environment and natural resources of each state.

6. Discussion and Analysis

6.1 Relevant Background Analysis

The demand for water and electricity in the communities involved has changed over time. The southwestern region of the U.S. is relatively infertile and still has a small amount of unused and underutilized land, but because of the presence of reservoirs, livestock and irrigated agriculture are well developed and people's use of water for production will not decrease in the short term. However, in the long run, the population migration trend in the U.S. is to the Northeast and South, which will produce some reduction in the population of the reservoir area in the later decade or two.

6.2 Sensitivity Analysis

A method for studying and analyzing the sensitivity of changes in the state or output of a system or model to changes in system parameters or surrounding conditions. When solving optimization problems, we often ignore the influence of the dependent variables in natural conditions on the model in order to facilitate model building. This allows us to determine the stability of the model or which parameters have a greater impact on the model based on the analysis of sensitivity.

We will perform sensitivity analysis on the changes of parameters in the following three scenarios. When the affected areas of population, agriculture and industry shrink, community demand for water will change, the reduction in water demand is recorded as r, not considering the change in electricity consumption according to environmental changes, set different values of r, and calculate the results. Draw a graph from the table as follows.

Table 4. Pumping capacity

r(af/day)	Pumping capacity(af/day)
20000	17329713
40000	17686129
60000	18061915
80000	18458694
100000	18878278

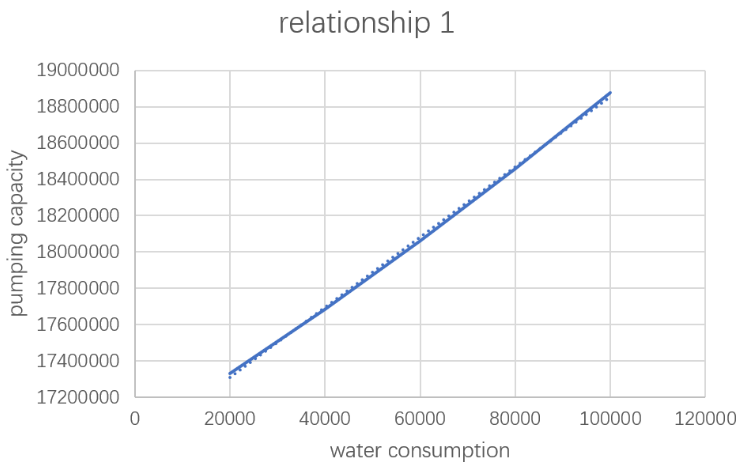

Fig.6 Relation curve

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7. Conclusion

In recent years, the drought in the southwestern United States has reduced the water available for dams and reservoirs in many areas, resulting in disruption of water and electricity supply, a phenomenon that has seriously affected the interests of the states around the reservoir. This paper mainly studies the water allocation between Glenn Canyon Dam (Lake Powell) and Hoover Dam (Lake Meade) under the current water reduction scenario. A nonlinear programming model is established to optimize the pumping distribution of each dam, and then the additional water supply required in a specific period of time is calculated. a nonlinear programming model is established to maximize benefits while meeting the water and electricity needs of five states. Finally, the sensitivity analysis to the change of surrounding conditions is carried out. Set parameters according to different background conditions, adjust the constraints or objective function of the model, and judge the stability of the model and which parameters have a greater impact on the model.

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